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## **Common Understanding of Life Management Techniques for Ageing Air Vehicles**

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### **Abstract**

Ageing aircraft are a growing problem in both military and commercial aviation. With the economic constraints of keeping current military and civilian aircraft in service, and the growing demand for air travel worldwide, the problems of ageing aircraft will continue to worsen.

The service life extension of equipment or a system over the initial design period is indeed a question of safety however, as the subsequent explanations show, this a question of efficiency and economy.

In a general sense, ageing aircraft are characterised by the deterioration of structural strength properties and the related problems and the increasing maintenance costs. Some of these problems are time dependent, such as corrosion, which also depends heavily on the usage environment. Others are usage dependent, such as in fatigue cracking, which is naturally caused by the mechanical loads that are introduced into the structure and also in electronic devices. Often the damage state of an aircraft is the result of both time (calendar years) and usage (operating hours). To maintain structural integrity, steps must be taken toward the prevention, detection, repair and prediction of the initiation and growth of aircraft structural damage.

What are now the valuation criteria for a decision for or against the further extension of the service life of an ageing aircraft?

The paper concludes with a view of future technologies, which could contribute to an expense-optimised useful life extension.

### **1. Introduction**

The combination of shrinking post Cold War Military Budgets and escalating costs for development and acquisition of new military aircraft have lead to increasing efforts world-wide to extend the operation of military aircraft far beyond their original design lives. Defence departments of even the wealthiest nations and nowadays also the poorer nations have begun to invest heavily in ageing aircraft programs. The intent of such programs is to preserve the integrity of aircraft structure and critical subsystems. The primary objective is to develop and transition technologies to further extend the life and/or reduce the cost of a weapon system forced to remain in service beyond its original design life. Sustainment refers to all activities necessary to keep the system operating except major modifications, modernisation projects or upgrades of existing subsystems.

One of the biggest challenges at the current time is the fleet management of a much bigger number of ageing aircraft. In 1993 already 51% of the US Air Force inventory are more than 15 years old and more than 20% had already crossed a life of more than 20 years. A look at the worldwide civilian aircraft makes clear the problem.

A/C Type	> 15 year [%]	> 20 year [%]	> 25 year [%]
A 300	43	9	-
B747 "Classic"	68	34	20
L-1011	80	49	6
DC-10	76	50	15
DC-8	51	51	51
B 727	80	53	32
B 727-100/200	71	35	21
DC-9	83	73	58
<b>Total</b>	<b>72</b>	<b>47</b>	<b>30</b>

Table 1: Civilian aircraft in service in 1997

Therefore more than  $\frac{2}{3}$  of the aircraft are older than 15 years and nearly half more than 20 years old. It is astonishing that still half of all the DC-8 ever built are still in service. We can expect similar results for the type DC-9 and the Boeing 727.

The purpose of this document is to provide an overview of the complexities of life extension, to discuss the general process involved in a life extension analysis, and to provide the reader with some guidelines to follow when trying to make the decision of whether or not life extension is a viable alternative to system replacement. The information presented is based on a review of the current literature, a consolidation of various system specific life extension procedures and discussions with individuals who are knowledgeable about or who have experience relating to life extension.

## 2. Life extension

Life extension, sometimes called service or system life extension, life cycle management or life optimisation has become an important topic of analysis in many of today's industries.

While life extension is of paramount importance to the utility industry, other industries also must and do consider life extension as an alternative to develop new systems. Even the military services are placing more emphasis on life extension, in light of declining budgets and reprioritised federal spending. No matter which industry is being considered, however, the incentives to save money and delay replacement of older systems are compelling. Yet, the risks and benefits must be carefully evaluated or the short-term cost savings will be offset by greater long-term costs, safety problems, or decreased system performance.

The primary focus is to maintain operational fighting capability by directing resources toward high payback technologies.

- That can identify structural deterioration
- That could threaten aircraft safety or degrade performance, prevent or minimise structural deterioration.
- That could become an excessive economic burden or adversely affect force readiness, assist in replacement of components.
- That can no longer be procured and assist in development of failure analysis and life predictive tools for such problems as fatigue damage, corrosion and stress corrosion cracking.

Systems and equipment are designed to have a certain service life. They are designed to perform one or more specific functions over a specified length of time or, in the case of one-shot devices, be capable of performing a function after storage or within a specific interval of time after manufacture, when operated and maintained according to some stated plan.

The oldest German Tornado will reach very soon the design life of 20 years in-service, where the aircraft runs out of certification. Considering a further planned usage up to the year 2028 for the Tornado IDS variant some IDS aircraft will stay in-service for nearly 50 years.

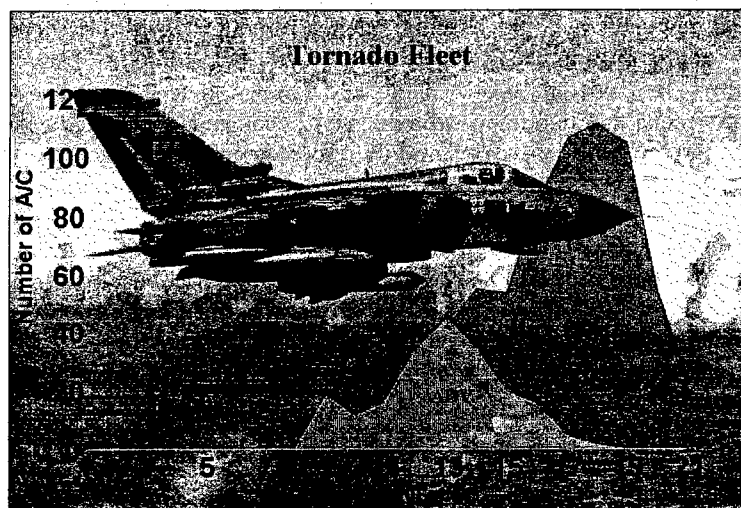


Figure 1: German Tornado Fleet

This does not mean that flight system components will remain in-service such a long time. Many equipment and components of systems are usually already been replaced during scheduled or unscheduled maintenance by overhauled, repaired or new items. A uniform in-service life for all system components in an aged aircraft does not exist. It is therefore important for critical equipment to record in-service operational and maintenance data in order to be able to assess the usage history and life consumption and define the point of retirement.

### 3. Reliability / Safety of the concerned items

The Reliability of the considered equipment decreases since the rear field of the bathtub curve is achieved because the ageing and/or wear caused malfunctions increases. In this way, the spare part demand and the number of the maintenance actions increases. These result in higher operating costs and reduced Availability.

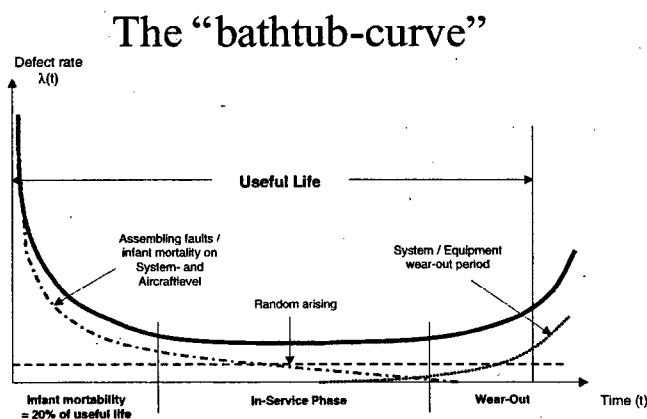


Figure 2: Bathtub curve

A measure within a life extension program would have to be determining the optimal point of time, when it is more economical to replace an item by a new part, a redesign or a modernised variant (upgrade) instead of to repair the old one again and again.

Therefore take into account, that so-called "old" equipment is often younger, than the aircraft cell/frame in which they are installed. Equipment will certainly fail during an aircraft life and one exchange is to be anticipated sometimes. To what extent-repaired equipment can then be classified, e.g. as a new value part, is also to be clarified. "Mixed equipments" are often to be found in an aircraft, where some single components have the original ageing, although other components have a younger date of manufacturer and/or days in use.

Decreasing Reliability also concerns the other aspect, Flight Safety. The use of a device after the specified life does not mean that the device immediately becomes not airworthy. Only the probability with which a failure can happen is increases and therefore the probability that a safety critical failure occurs!

However, in general the specification required the avoidance of safety critical failure, e.g. by bringing in redundancy within the equipment or on system level. Furthermore, the supplier has to provide proof that safety critical or safety relevant failure does not exceed a defined probability.

The proof is guaranteed normally by the preparation of Fault Tree Analyses (FTA), Failure, Modes, Effects and Critically Analyses (FMECA) and/or Defect Rate Prediction Reports.

#### 4. Verifications of the trends at the example Tornado

To give an overview of the ageing-conditional failure rate of the different basic systems in a period of 10 years, an analysis of the documented defect data was carried out at the example Tornado.

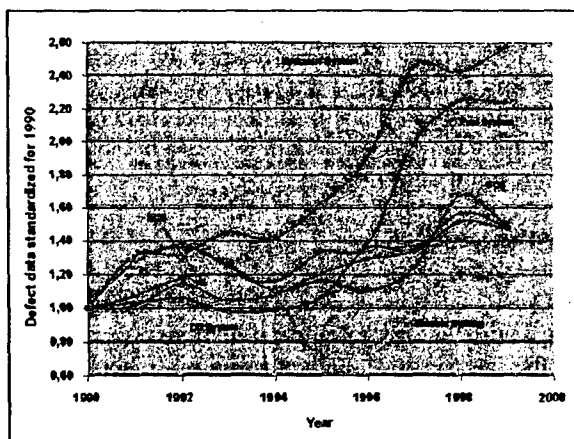


Figure 3: Document ageing-conditional in-service defect data standardized for 1990

The trend curves were constructed with the help of the in-service defect data for which corrosion, leakage, non-sealing and wear was identified as a failure cause.

The analysis was executed for the following basic systems:

- Landing Gear System (LGS)
- Flight Control System (FCS)
- Electric Systems
- Fuel System
- Hydraulic System
- Environmental Control System (ECS)

At this point should be mentioned that the analysis of the defect data is complex. Frequently no secured and sufficient descriptions of the failure cause are available. Therefore assumptions must often be met in the evaluation. A trend can nevertheless be derived from the curves, which confirm the increase of the failures in relation to the useful life.

A significant increase of the failure rate comes out from the examinations within the last 10 years.

So the failure rate increased for Hydraulics System by 160%, for the Fuel System about 120% and for LGS, FCS and ECS about approx 50%. For the structure / cell arises a similar picture.

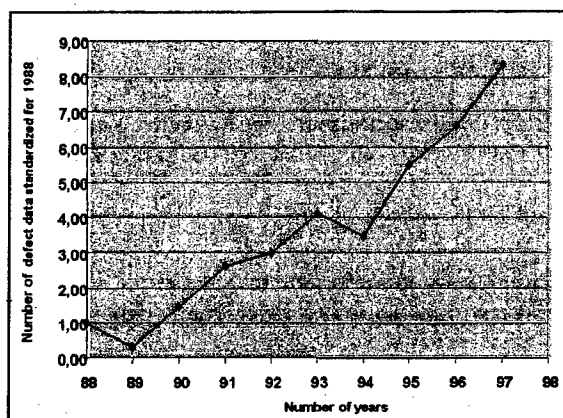


Figure 4: Result of the defect data with regard to the cell/airframe for the period 1988 to 1997 standardized for 1988

An accompanying analysis of the inspection distribution expenditure shows Figure 5. Therefore the biggest interest approx 61% fell in 1980 to the visual inspection, while the scheduled and unscheduled life extension measures contributed to 8% respectively 31% to the whole inspection expenditure. The unscheduled life extension measures are measures, which are respectively on the examination of repaired components parts or components parts with supposed failures.

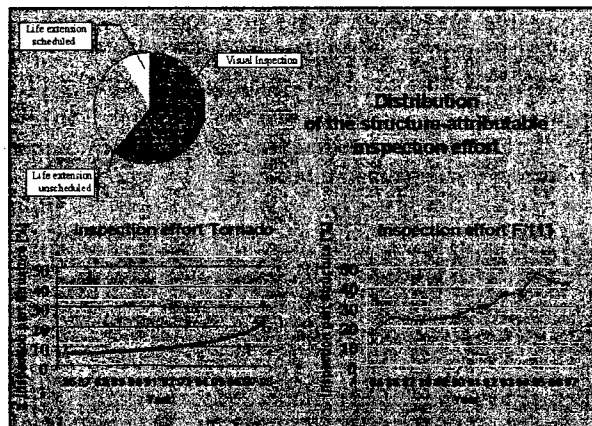


Figure 5: Distribution of the structure-attributable inspection effort

An examination of the distribution, which reflects the period of the last 5 to 10 years, shows an unambiguous shift. Therefore not only the quantity of inspection instructions has increased, but the distributions of the inspection demands have changed. This stands in the direct connection to the represented increase of the basis failures in Figure 3 and 4.

## 5. Ageing Mechanisms

Ageing is understood as a process, where the structural and/or functional integrity of equipment/components will be continuously degraded by the exposure to environmental conditions, under which the equipment is operated.

This could lead in the worst case to a situation where the aged equipment cannot fulfil any more its design function; even before the design life of the equipment is reached. In this case, system functions, which the equipment has fulfilled or supported, could be lost or degraded, which may also affect Flight Safety.

There are various mechanisms, which alone or in combination are responsible for equipment/component ageing.

- The exposure to normal or salty atmosphere, heat, water, oil, fuel, etc., which could lead to corrosion, overheating, melting or other material degradation, electrical interruptions, short circuits, etc..
- The exposure to vibration and acoustic environment, which could lead to fatigue damages, wear and tear, etc..
- The endurance, which lead to leakage, wear and tear, etc..
- The maintenance activities, which can induce accidental damages, could be a particular problem for wiring.

It is likely that Reliability and Availability of the equipment will be impaired by these influences.

Additionally, incorrect installation of equipment could also have a detrimental effect and support the ageing process, e.g. enable scouring of wire bundles on surrounding structure (this can be a result of poor design but also of poor maintenance).

Aged equipment/components will be removed from service, if further use is not recommended for Safety reasons or if further safe operation is uneconomical due to required inspection and maintenance activities.

Life expired equipment/components can be defined by the fact that any specified and certified life limitations are reached by the in-service usage and therefore need to be replaced.

Life extension might be possible and needs to be investigated. In the event that the design and certification authority permit further on aircraft operation under clearly defined conditions, further use of the equipment can be tolerated without formal re-qualification and for a limited time. As the aircraft runs out of certification (e.g. Tornado > 4000 FH) and the formal certification process up to 8000 FH has not been completed yet, the definition of such conditions and requirements for further usage up to 5000 FH is e.g. part of the Tornado life extension program.

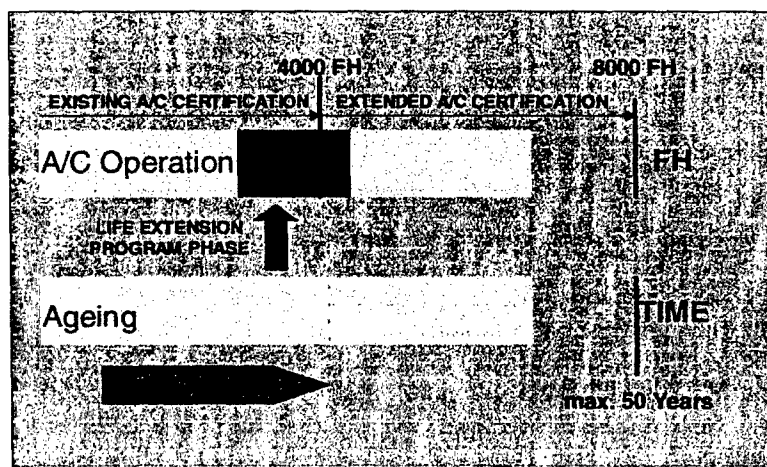


Figure 6: Life extension demand

## 6. Influence of maintenance on ageing

As already mentioned, ageing of equipment/components cannot be prevented but slowed down. It is reasonable to say that if maintenance is poor or not timely conducted certain ageing effects (e.g. corrosion, contamination, wear and tear, etc.) could be accelerated or even induced.

This means that the physical condition of aged equipment/components in different aircraft can vary due to different quality of maintenance carried out, which could result in earlier retirement of components than assigned. When investigating the condition of wiring in different aircraft from different Nations this aspect became obvious.

Aircraft maintenance programs will always be a compromise as beside other logistic costs and overall fleet management are important issues. It is important to include preventive maintenance actions for critical equipment and areas in the existing maintenance procedures to ensure that ageing problems will be detected at an early state, where the effort for repair is still acceptable and an airworthiness critical situation avoided. This may lead to shorter intervals in periodic servicing schedules or in special inspections.

So within equipment Life Extension Program ageing effects on equipment/components should be investigated as far as they are obvious and known. The manufacturer, to establish revised maintenance procedures for his equipment, where necessary, will use the results of that investigation.

## 7. Problems with increased aircraft age

There are some factors that have an effect on the problems associated with aircraft ageing, e.g. the usage of the aircraft, the environment the aircraft is subjected to and the inspection and maintenance practices and tools.

Depending on how an aircraft is used, the aircraft may have an expended life significantly different from what is predicted for that aircraft at that time. The simple fact is that aircraft are often not used the way they were intended to be use when they were designed and commissioned into the fleet. The effect is that an aircraft that is used harder than expected will have higher cumulative equivalent flight hours than expected. As a result, that aircraft may have a higher damage state than is predicted and may have a correspondingly higher probability of failure.

Depending on where an aircraft is used, an aircraft will have corrosion problems from the environmental conditions. This is most prevalent for military aircraft. Military aircraft that are stationed near saltwater environments experience a higher degree of corrosion than other military aircraft.

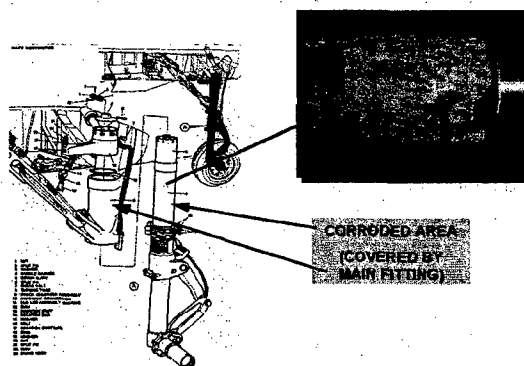


Figure 7: Corrosion Main Landing Gear Shock Absorber

The predisposition to corrosion depends, additional to environmental conditions, on further factors:

- Corrosion resistance of the material
- Combination of material
- Surface protection and sealing material

The problems, which can hang together with corrosion, have the following causes:

- Penetrations of humidity in the structure in case of faulty coat of varnish and sealing materials.
- Penetrations of humidity in (dry) hollow cavities
- Lack of adequate ventilation and drainage
- Choice of a not optimal surface protection and sealing material
- Contaminated fuel

However, these military aircraft are probably the most carefully monitored and cared for aircraft as far as corrosion is concerned.

Besides the ageing problematic other topics, which are not related to ageing but cause problems in an aged aircraft, need to be considered and investigated:

- Usage history, life consumption

As required by formal certification rules, equipment, which exceeds stated life limits are formally out of certification. Therefore, the usage history needs to be established and this requires the Availability of complete in-service documentation (FRACAS, Maintenance documentation).

Unfortunately, it has been experienced that it is sometimes very difficult to get all the information, which is required to assess service life and life consumption. For Safety relevant and life limited components this causes many problems, as it might be not possible in these cases to establish whether equipment is already life expired or not.

- Repairs and concessions

The influence of repairs and concessions on life limitations needs to be assessed.

Normally, minor concessions should not affect life limits, but if the operational conditions have changed in the past, the classification of concessions needs to be reassessed.

- Obsolescence

Obsolescence is a problem, which becomes more problematic with increasing age of the aircraft.

Materials and components, which have been used in the original design, could be no more available and this could require re-design and re-qualification activities if no proofed and certified alternative exists. Especially for electronic parts obsolescence is a critical and costly issue. The technology progress over the last 20 years was so enormous that certain items are only still be available in a limited quantity. A strategy for future support of that equipment needs to be established.

- Availability of original supplier

For most equipment there was only one supplier selected, who has designed and qualified the item.

This supplier might have disappeared or no more able to produce the required equipment. Introduction of alternative supplier will cause problems in terms of time and costs. Dependency on one supplier is critical but usual.

- Costs for procurement of equipment

The procurement of equipment for replacing aged or life expired equipment after 20 years in-service could be very costly as e.g. original suppliers are no more existent, design and qualification of new components are necessary or the required number of equipment is very small.

- Costs for maintenance actions

The expenditure for maintenance rises continuously for the operation lifespan. S.G. Sampath published an examination about the maintenance expenditure of the F 111A. Approx 2200 Man Hours (MH) per aircraft were required in 1985 for the execution of inspections and repairs. In 1996 the expenditure was estimated for the maintenance the F-111A already at 8000 Man Hours (MH).

## - Failure and maintenance reporting systems

Most aircraft users maintain comprehensive databases to collect and evaluate failure and maintenance reports for the whole aircraft down to equipment and component level in order to identify unreliable equipment and other problem areas. In the German Forces we have established the tool WIDAV (Maintenance / Inspection In-Service Defect Data Acquisition and Evaluation System). In our Reliability department we have established a special Failure Reporting Analysis and Corrective Action System (FRACAS) tool called DEMON (Deviation Monitoring).

However, in-service data collection systems are mainly defined by the aircraft users and reflect their specific needs and points of interest. The definition of data elements and the level of detail may significantly vary, even between the different users of the same aircraft type.

For this reason, the probability, that failure and maintenance data collected during service is compatible with design analysis and predictions is fairly low.

Moreover, in-service data are not always available to the system design authority at a required level.

The value of an in-service database can only be as good as the input data. It is therefore important to consider that any analysis or curves derived from databases needs specific interpretation and should be taken with care.

The major "lessons learnt" for future data collection systems are therefore continuous availability to both user and manufacturer and the need for compatibility with design analyses, in order to gain maximum benefit over the aircraft lifetime.

## 8. Concept for ageing aircraft

For a total concept the problems appearing during the qualification (service life test), as well as the effect of the combination by material fatigue and corrosion must be considered.

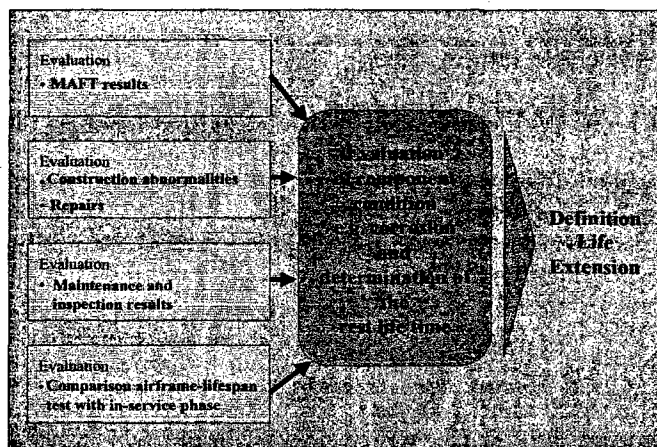


Figure 8: Concept to the preservation of the structural integrity beyond the original design lifetime.

The continuation of the extension of in-service life can be reached in principle by different measures:

- Exchange of parts to a fixed point of time
- Incorporation of a simple lifespan increasing modifications (how cold worked of drillings and surfaces)
- Combination of inspection and exchange to minimize downtimes.

In principle some of these life extension measures can be executed with the regular small and big inspections.

### 8.1 Evaluation of repairs and construction abnormalities

During the in-service time of an aircraft individual repairs are inevitable.

Reasons for this are e.g.:

- Damages cover in the flying operation by wear, hard landings, accidents...
- Bird strikes
- Damages during the maintenance
- Re-equipments
- Corrosion

Repairs are defined or are judged normally for the full design loads in regard to the demanded lifespan, just as the construction abnormalities appeared during the production. Otherwise an entry would be required in the logbook of the aircraft.

### 8.2 Evaluation of inspection and maintenance results

During the aircraft utilization phase a database for structural defect data should be established. With the help of the database recurring defects can be identified and thru measures reduced or removed.

Special measures should be considered:

- Corrosion including tank-space corrosion
- Wear
- Edge erosion in fibre construction units,
- Damages in small parts
- Damages in maintenance-intense areas

as well as:

- Damages in connecting elements
- Damages in hardly detectable structure areas

### 8.3 Comparison of the airframe-lifespan test (MAFT) with in-service phase

A re-valuation of the results of the Major Airframe Fatigue Test (MAFT) is executed by comparison of the introduced test loads with the real in-service spectra.

So it is possible, e.g. that spectra are lower in the flying operation than in the MAFT-test, but the individual component part damage is higher.

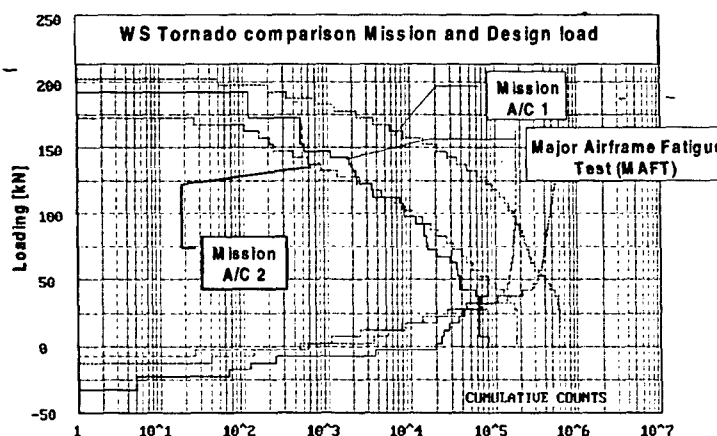


Figure 9: Comparison Mission and Design load at the example Tornado

## 9. Technological inception to life extension

A life extension requires a high expenditure in Man Hours (MH), in the definition, retrofit as well as in the future maintenance. The use of new technologies can reduce the expenditure by an aimed operation and herewith carries to an expense-optimised life extension for ageing aircraft. At this point only three technologies are named which possess a high potential to optimise life extension and maintenance cost.

These are:

- Automation of inspections
- Introduction of a Health Monitoring System
- Monitoring of critical component parts by the use of sensors (Damage Monitoring)

### 9.1 Automatically inspections

How already in chapter 4 represented the inspection expenditure rises continuously for the maintenance of ageing aircraft. The automation of inspections, by means of inspection robots, allows the reduction of the test expenses by the substituting man for machine and the direct data processing. This technology is also advantageous from a safety point of view where a danger to the technicians might exist.

However, at the moment the acquisition of an inspection robot is still expense-intensive, on account of the high expenditure to the navigation, control and image processing. But in the future cost might sink. The subject of inspection automation is mentioned only of the completeness. No following information are available at that point.

### 9.2 New Philosophy

A new philosophy will be the installation of the Damage Tolerance concept.

Distinction:

- "Safe Life" means that a structure sustains a specified period of lifetime without cracks (no inspections).
- "Damage Tolerance" is the property of a structure to sustain defects or cracks over a specified period of lifetime.

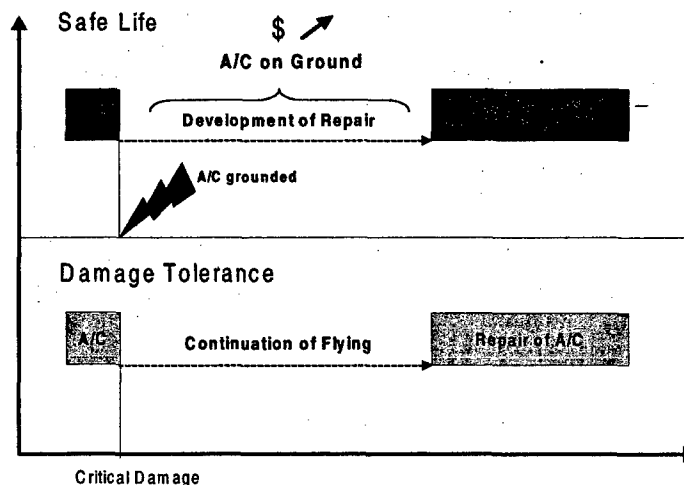


Figure 10: Comparison of Safe Life and Damage Tolerance Philosophy

Which are the advantages of Damage Tolerance Philosophy in respect to Safe Life Philosophy?

- Increased service life, "Retirement for Cause," (significant cost savings for customer)
- Increased ratio between Safety and Structural Measures
- Better planning of structural maintenance, better Fleet Management and individual aircraft tracking (significant cost savings)
- Increased Operational Readiness
- Better handling of upgrades and increased usage scenarios

### 9.3 Usage Monitoring

Usage Monitoring stands for:

- A monitoring of the structure and systems with the aim to steer the scheduled material-preservation-measures and to guarantee therefore an optimised fleet management.
- For the monitoring of the events which can lead to unscheduled measures, how e.g. Over-g or hard landings.

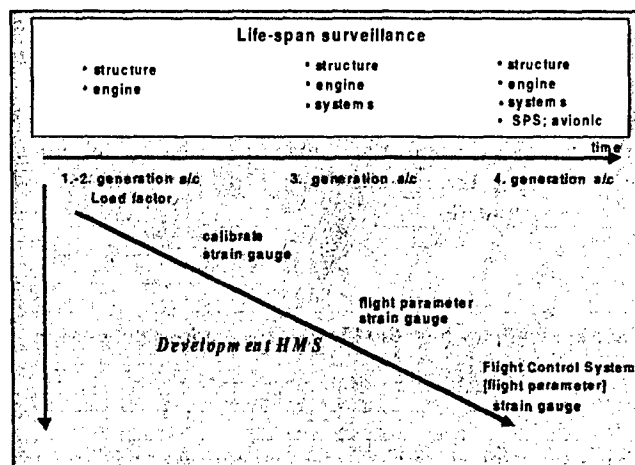


Figure 11: Overview Usage / Health Monitoring development

There are different options to realize Usage Monitoring.

- Development and integration of a reasonable Usage Monitoring which offers the possibility for trend analysis or
- Development and integration of an efficient Usage Monitoring as an integral component of the avionics structure [on aircraft or off aircraft].

### 9.4 Future Usage Monitoring systems

The trend in the development of Usage Monitoring systems goes unambiguously to the integration in the avionics structure of an aircraft. In this connection, one uses the possibility that the IPU (Interface Processing Unit) can provide all flight data. Therefore all relevant flight parameters of the data buses (FCS: Flight Control System, UCS: Utility Control System, AVS: Avionic System) are available for the calculations.

For example, the Eurofighter Usage Monitoring is subdivided:

- Engine Usage Monitoring
- Structural Usage Monitoring
- SPS (Secondary Power System) Usage Monitoring
- Aircraft-System Usage Monitoring

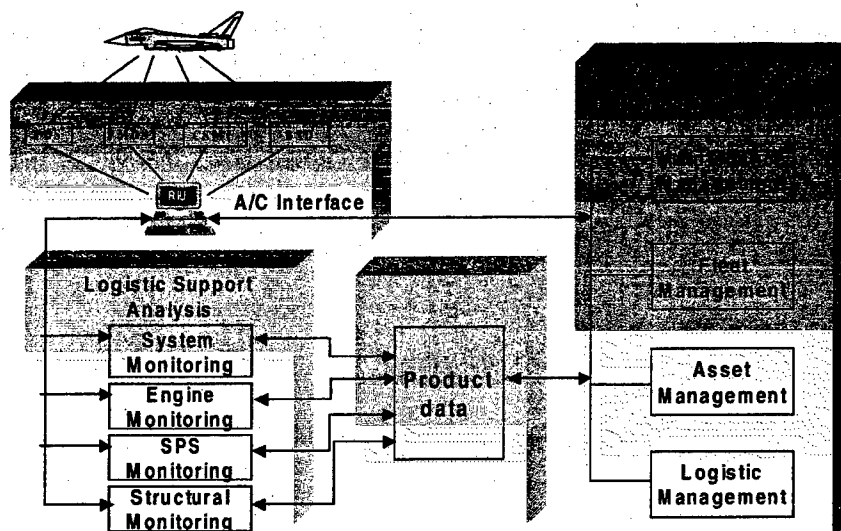


Figure 12: Data processing at the example Eurofighter.

### 9.5 Health Monitoring

With the development of microelectronics new ways are presented to monitor structures and systems by means of sensors. Today we are in the position to be formed the dimensions and the Reliability of the sensors so that they can be used at reasonable price in the application for the monitoring of weight-optimised structures. Also increased computer-performance offers the possibility of fast signal processing. Therefore the possibility insists to specify the on-condition inspection as an integral part of a Health Monitoring system and therefore the maintenance additionally optimised, i.e. reduction of the Life Cycle Costs. In the technical literature one speaks of Damage Monitoring. Within an integrated Health Monitoring system the on-condition inspections would automatically be executed. The resulting advantages being e.g.:

- Avoidance of expense-intense conventional inspections life extension in hardly accessible areas
- Increase of the inspection intervals
- Increase of the Availability of aircraft
- Increase of the useful life without direct repair measures

The principle of a Damage Monitoring system consists of sensors, signal-amplifier, filter and signal processing. This concept allows the collection of signals, which are caused by the damage directly (comparison of the loads before and after the damage event).

Concerning the collection of the signals all sensors are suitable which are able to measure frequency, which are produced by loads or damages. Three types of sensors are suitable particularly for an integrated Damage Monitoring.

These are:

- Fibre-optical sensors
- Piezoelectric sensors
- Sensory folios

Fibre-optical sensors are interesting because of their low weight, low power demand, long lifetime and low expense. Fibre-optical sensors have particularly proved themselves in damage identification by means of acoustic emission. The possibility to imbed in fibre composite materials is a special advantage.

Piezoelectric sensors are used traditionally to measure acceleration, which result from low or high frequency (vibrations). The piezoelectric sensors are producible in almost arbitrary size. With the help of this technology new applications and possibilities of structural monitoring arise. A very promising application in the aircraft construction is the use of sensory foils. In this connection, thin piezoelectric sensors are embedded together with the wiring between thin foils. These foils can be bonded onto the structure or be embedded in a fibre group structure.

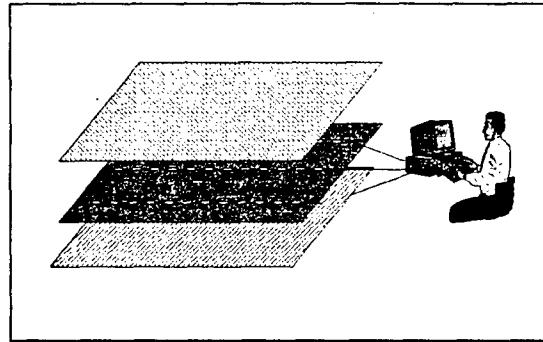


Figure 13: Construction of a sensory foil.

With the use of sensory foils a new level of on-condition monitoring is exhibited.

The damage monitoring could then become an integral component of lifespan-monitoring. It would be possible to monitor CFC (Carbon Fibre Composite) repairs. Therefore life extension and scheduled maintenance measures could be defined. It would be possible to maximize the lifespan and to optimise the retrofit point of time.

## 10. Conclusion

With a high probability the use of an aircraft changes during the whole operation lifetime. Therefore, it is necessary that the flight operation is monitored continuously by individual measurements and on-condition inspections. Only thus can Mission Reliability of the aircraft within the qualification or certification be guaranteed.

The Life Cycle Costs (LCC) prediction considers the increase at the end of the design lifetime. But no LCC development predictions existed when an aircraft oversteps the defined design lifetime. As already mentioned an increase of the life cycle cost is expected, which is caused by increased inspections, scheduled and unscheduled repair measures. A definition of the life extension measures must consider these aspects. So the aircraft can be further operated economically.

Life extension measures are inevitable with ageing aircraft. In the definition of the life extension measures the maximization of the remaining lifespan and the optimisation of the life extension retrofit point of time is the aim. Only then can a flexible fleet management be offered. A Health Monitoring System could perform here an essential contribution. With an HMS the maintenance measures could directly help support the material preservation. On-condition inspections become an integral part of the lifespan-monitoring.

In conclusion it should be mentioned that a Usage Monitoring is necessary during the utilization phase. A Health Monitoring System need not be employed at the beginning of the in-service phase. The damage monitoring should nevertheless be a modular part for the development of a new aircraft. That is the basis for an economic integration of the damage monitoring as supplement to the Usage Monitoring of the aircraft. The retrofit of a Health Monitoring System in existing ageing aircraft should also be taken into consideration. But it requires a cost-benefit analysis to justify investment in a Health Monitoring system.

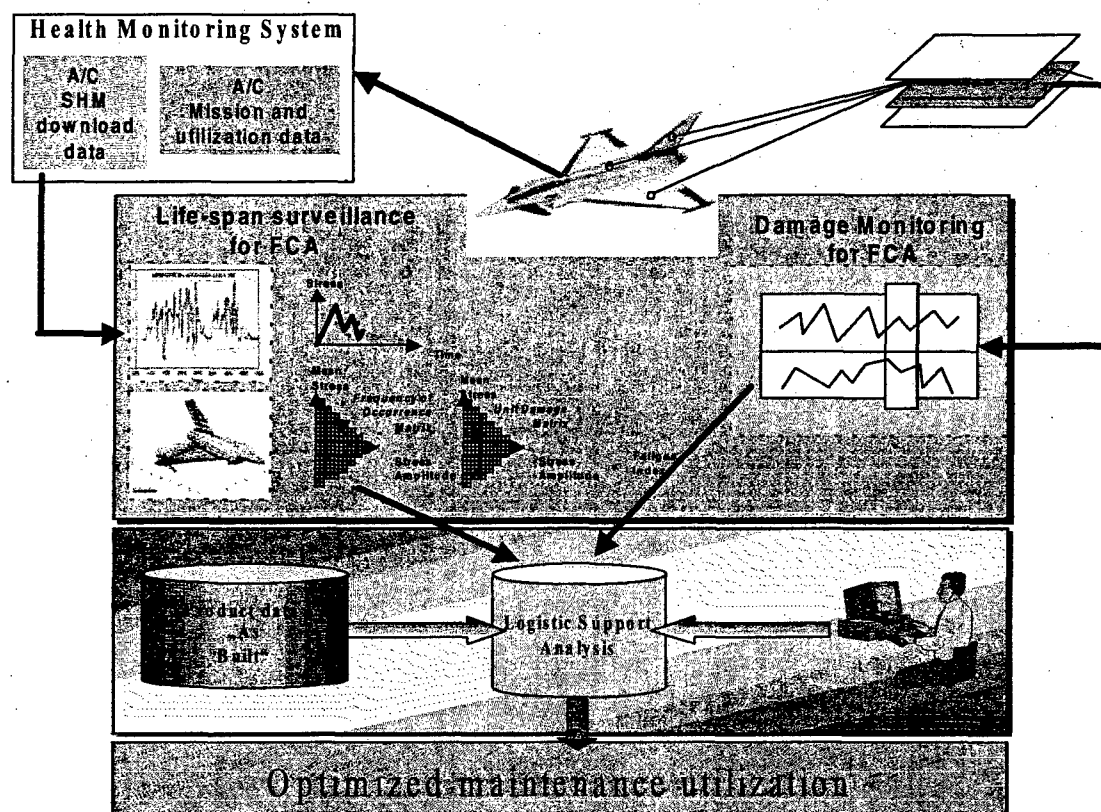


Figure 14: Total concept of the load and damage monitoring at the example Eurofighter

## References

- "Service Life Extension Assessment", Ned Criscimagna, Richard Unkle, Reliability Analysis Center, Rome, NY, USA, September 1995.
- "Aging Aircraft Subsystems Equipment Life Extension within the Tornado Program", G. Blech, PANAIA Aircraft GmbH, Hallbergmoos, Germany
- "Transall C-160 Life Extension and Avionics Upgrade Programs", P. Blumschein, EADS Germany GmbH, Manching, Germany, April 1999.
- "Aging Combat Aircraft Fleets – Long Term Applications", S.G. Sampath, 1996
- "Philosophien in der Entwicklung und Definition von Nutzungsdauerverlängerung am Beispiel Tornado und die daraus folgenden Auswirkungen auf die Instandhaltung", M. Buderath, EADS Germany GmbH, Ottobrunn, Germany, June 2001